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Director, *CRUSER*

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UNSECNAV Guidance

- **UnderSecretary of the Navy Work – 1 Feb 2011:**
- **"…to shape generations of naval officers through education, research, concept generation and experimentation in maritime applications of robotics, automation and unmanned systems……."**
- **"……provide a DoD-wide community of interest to exchange research and experimentation results"**

Organization

Oversight

- Sponsor: SECNAV
- Funding: ONR
- Off Campus Steering Group
- On Campus Advisory Board

Coordination

- **Ray Buettner** Director
- **Dr. Timothy H. Chung** Director of Research and Education
- **Carol O'Neal** Director of Innovation and Concept Development
- **Lisa Trawick** Operations Manager
- **Lyla Englehorn** Program Manager

CRUSER CoI

- NPS Faculty/Students: 311
- DoN: 283
- Industry: 240
- Other Government: 103
- Academia: 90
- USA/USAF: 35
- General Public: 24
- International: 23

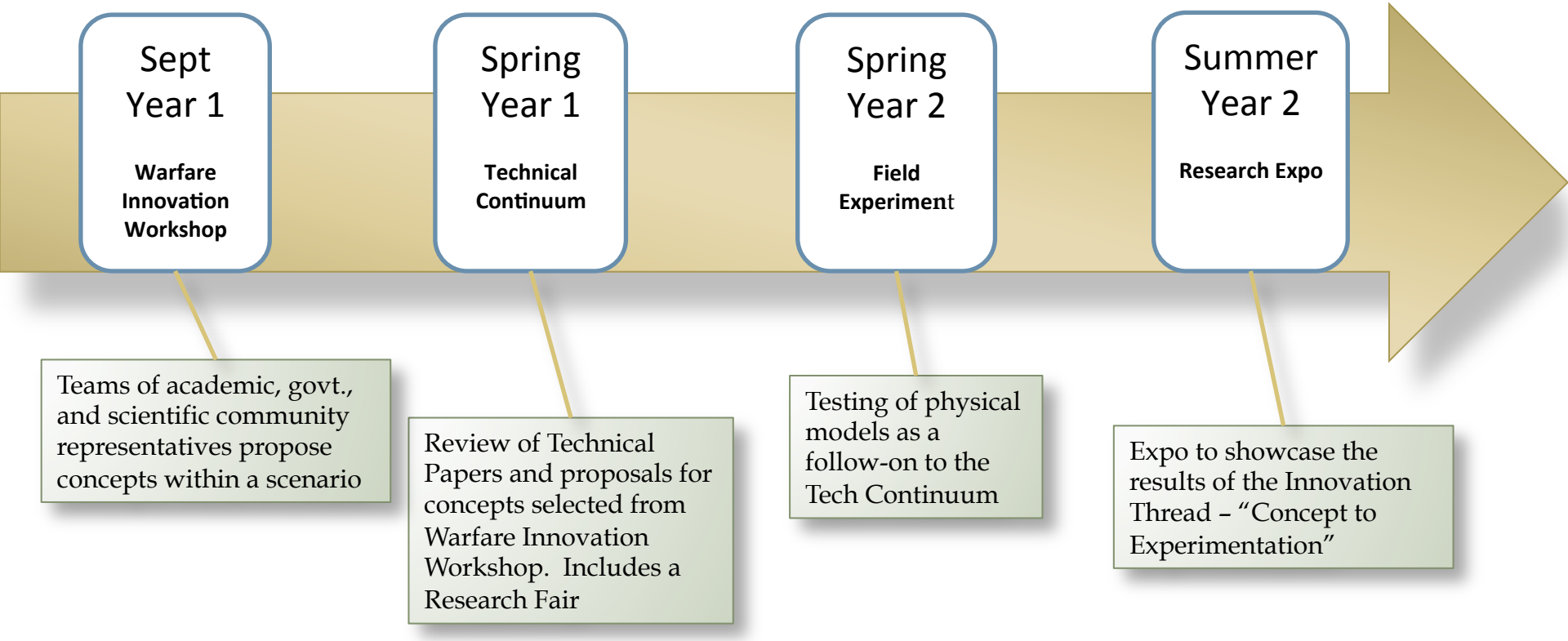
Over **1100** Members and growing

FY11-FY14 Objectives

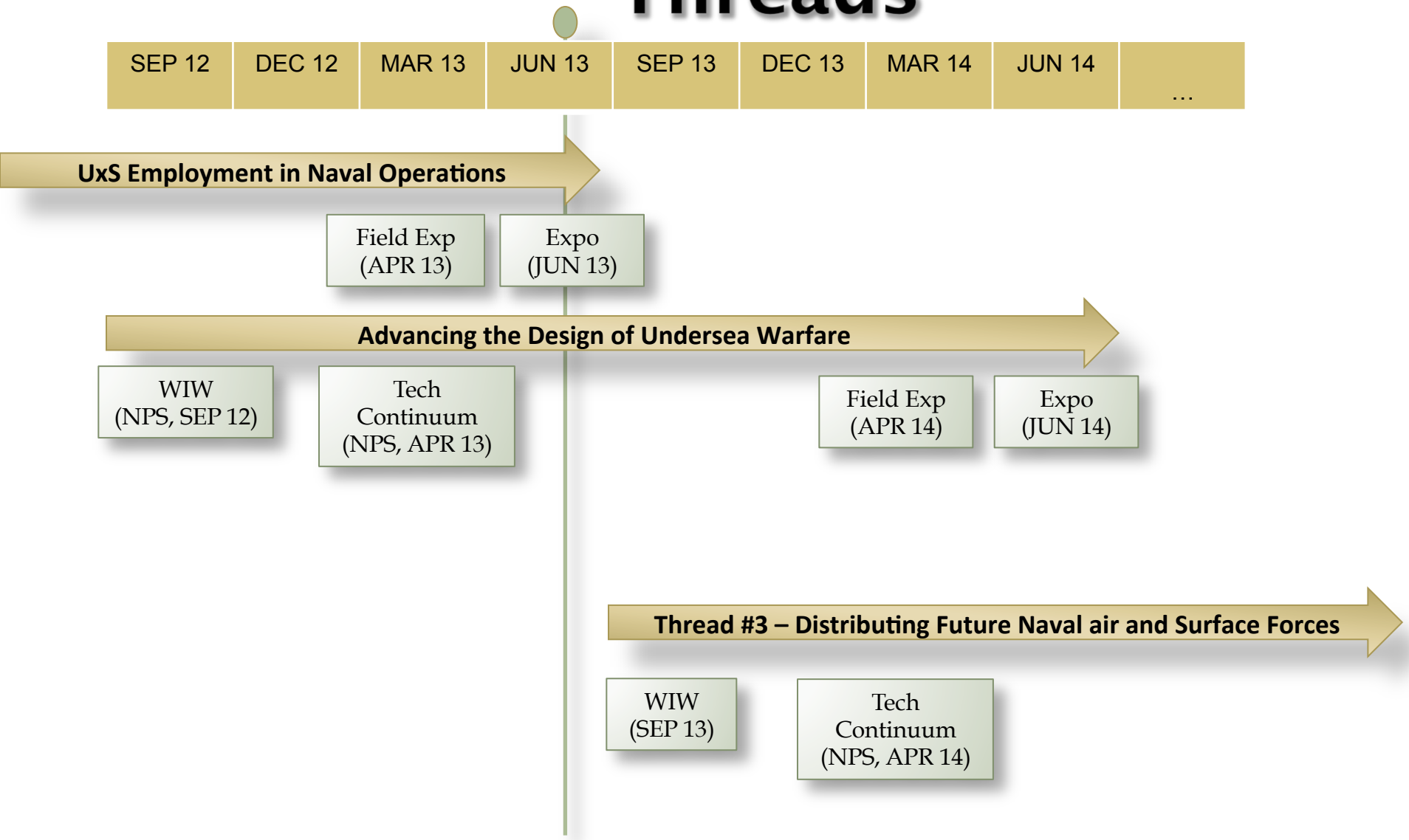
- Concept Generation
- Experimentation Program
- Education Venue
- DoD-wide forum for collaboration

Innovation Thread

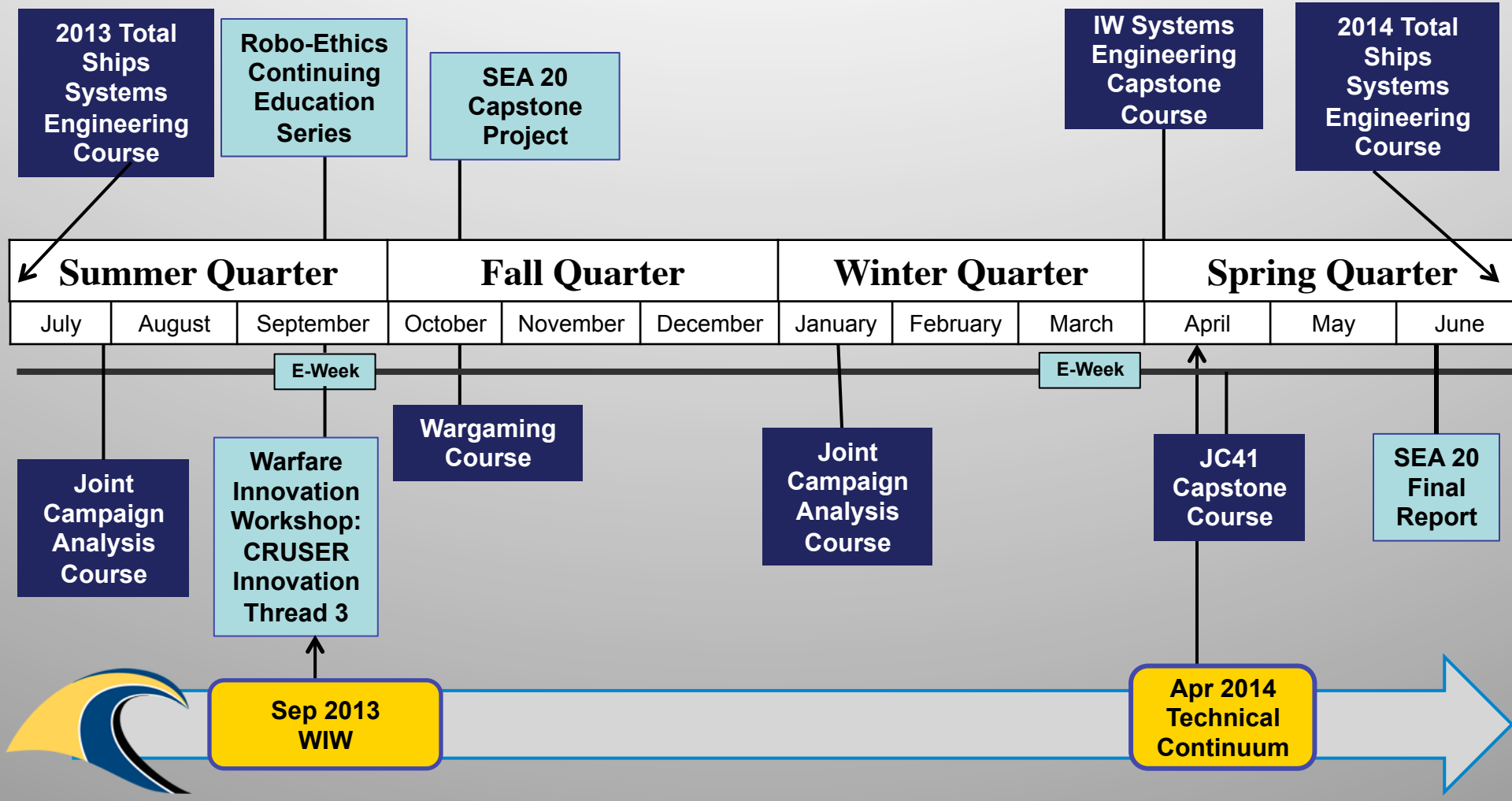
A two-year event cycle starting in September with a Warfare Innovation Workshop and ending with a research presentation at ONR showcasing the results of the innovation thread



Current Innovation Threads



Warfare Innovation Continuum
"Distributing Future Naval Air and Surface Forces"
Concept Exploration and Development



CRUSER Innovation Thread Three: "Distributing Future Naval Air and Surface Forces"

Concept Generation - Warfare Innovation Workshops

Sept 2010 – Advanced Undersea Warfare Systems (AUWS)

Mar 2011 – Future Unmanned Naval Systems (FUNS) Wargame Competition

Sept 2011 – UxS Employment in Naval Operations

- Revolutionary Concept Generation from Evolutionary UxS Technology Changes
- Four teams of NPS students, early career engineers from Navy Labs and industry
- Identified over 40 revolutionary concepts
- Five areas identified for presentation at May Tech Continuum:

Counter-UAV **Info Assurance** **ISR** **Non-kinetic Strike**

Knowledge Management/Data Management

Concept Generation:
"UxS Employment in Naval Operations"

Selected Concepts:

1) **Counter-UAV measures:** UAVs that specifically threat other UAVs – such as an expendable "hunter-killer" UAV for defense of allied forces.

2) **Low possibility of intercept (LPI) comms:** covert and innovative networks – such as the "Digital Semaphore" concept being taken to field experimentation in FY13.

3) **UxS support of ISR missions:** Tagging and tracking operations, innovative surface and subsurface observation platforms.

4) **Bandwidth and data management:** Advanced algorithms for "information triage" or onboard/in situ processing to reduce network loads, and improved data farming of meta-data.

5) **Non-kinetic strike operations:** UxS employed in non-kinetic operations to disable enemy assets – such as fouling agent deployment, jamming or spoofing/decoy operations.

Technical Continuum

TOPIC	SPEAKER
Project MISSION: Maritime In Situ Sensing Inter-Operable Network	Professor Joe Rice, NPS
Wave Powered Unmanned Surface Vehicle Operation in the Open Ocean: a station keeping asset for distributed netted systems	LT Timothy Rochholz, USN
Mine Burial Expert System for Changing MIW Doctrine	Dr. Peter Chu, NPS
Channel Modeling and Time Delay Estimation for Clock Synchronization Among Seaweb Nodes	LCDR Pascal Gagnon, RCN
NILUS – An Underwater Acoustic Sensor Network Demonstrator System	Dr. Roald Otnes, FFI
Underwater Acoustic Network as a Deployable Range	ENS Rebecca King, USN
Tailorable Remote Unmanned Combat Craft (TRUCC)	LCDR Loren Jacobi, USN LT Adam Bush, USN
Countering Inundation with Innovation: Defeating Swarm UAV Threats with Aerial Combat Swarms	Dr. Timothy Chung, NPS
Autonomous System Support for Maritime Visit, Board, Search and Seizure Operations	Dr. Noel du Toit, NPS
Emerging Applications of 4K Ultra-high Resolution Full Motion Video for Unmanned Systems and Remote Sensing	Jeff Weekley, NPS
Digital Semaphore	Dr. Don Brutzman, NPS

- 7-10 May 2012
  - Held in conjunction with Tenth International Mine Warfare Symposium
- Industry and Navy labs invited to demonstrate technical capabilities related to the selected topic areas
- Two concepts selected for continued development and field experimentation:

Aerial Combat Swarms

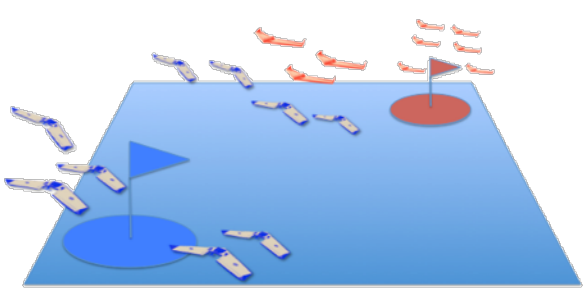
Digital Semaphore

Aerial Combat Swarms:

Swarm vs. Swarm UAV Competition

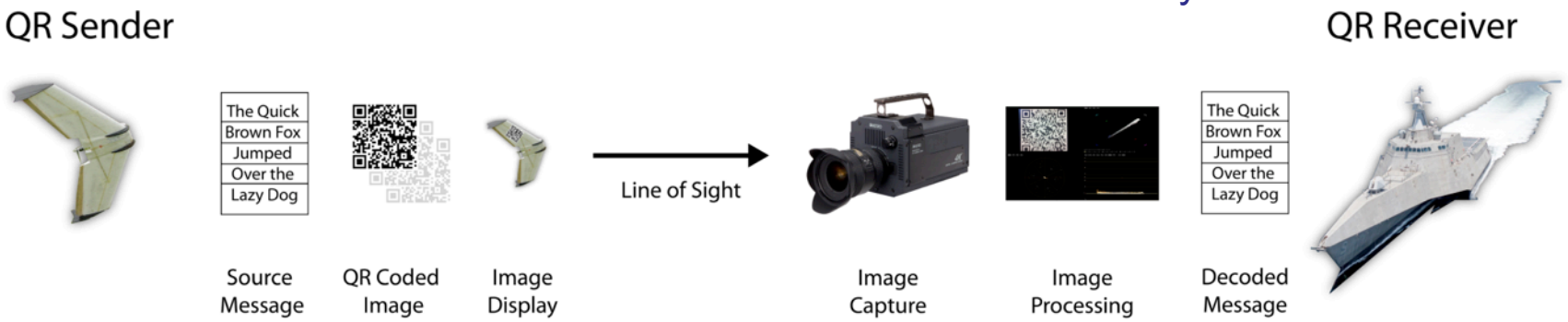
A grand challenge where *tactics drive the technology*

- Develop enabling capabilities for **attacking** the opponent's aerial bots and their home base while actively **defending** own home base
- Conduct **live-fly, outdoor competition** in tournament-style event
- Seek **innovations** in tactics, concepts of operations, autonomy algorithms, hardware platforms, etc.
- Provide **common standards** and infrastructure for rapid evolution



Digital Semaphore

Developing Novel Approaches to Quick Response Code (QR Code) Image Acquisition using 4K Ultra-high Resolution Video for Fleet Tactical Communications with Unmanned Systems



Initial results: Demonstrated QR codes can be extracted at distances at least 500 times farther than typical (600' versus 1-1.25').

Findings: Many controllable factors - QR encoding, QR display, sensor, optics, image processing, data processing can all be adjusted based on conditions. Additionally, Dynamic QR Codes for streaming and moving capture are possible.

Recommendations: Continued Research Warranted - Adaptive Optics to Extend Range past 10K yards, Software for Encode/Decode and Image Processing, Continued Field Testing with Unmanned Systems

Research Fair

Under Secretary of the Navy the Honorable Robert O. Work with LCDR Loren Jacobi, NPS Student

Carmel High's FIRST Robotics robot

- 10 May 2012
- Held in conjunction with the CRUSER Technical Continuum
- Over 20 exhibitors from NPS, DoD, industry and international militaries
- S.T.E.M. event
- Research showcase

Research Expo: Washington DC

- Venue to showcase the results of CRUSER Innovation Thread #1, UxS Employment in Naval Operations
  - Concept Generation:
    - Sept 2011 Warfare Innovation Workshop
  - Field Experimentation:
    - Aerial Combat Swarms
    - Digital Semaphore
  - June 2013 at ONR

Warfare Innovation Workshop: Concept Generation

- "Advancing the Design of Undersea Warfare"
- 17 – 20 Sept 2012
- Sponsored by NWDC, NUWC and CRUSER
- Directly supports the NWDC Line of Operation in developing the DUSW

- Focus on employment of the Undersea Warfare Operating Concept in the War at Sea Strategy
- Junior officers from NPS and the fleet, early career engineers from Navy laboratories and NWC SSG Director Fellows
- Innovative Concept Generation for leveraging U.S. strengths in the Undersea Domain to counter A2AD in Phase 0/1

Concept Generation:

"Advancing the Design of Undersea Warfare"

Selected Concepts:

1) **Decoys and military deception (MILDEC):** Designs to obfuscate targeting or cloud the enemy's operational picture – such as a USV swarm fleet or acoustic deception by unmanned systems.

2) **Vessel tagging:** For domain awareness and tracking – such as remora tag with hydro-fan generator.

3) **Non-lethal kinetic effects:** Generation of non-lethal stopping tactics and mechanisms – such as condenser fouling agents.

4) **Undersea positioning, navigation and timing:** For navigation accuracy and domain awareness as an alternative to GPS and surrogate for underwater use.

5) **Undersea "garage":** Autonomous docking, power generation and transfer, deployment and to extend time on station.

6) **Hybrid unmanned vehicles:** Multi-domain vehicles that transition between domains.

7) **Crowd-sourcing:** Leveraging white shipping, regional fishing fleet and other entities to meet mission data collection needs.

Concept Generation:
"Undersea Superiority 2050"

- 25 – 28 March 2013 Warfare Innovation Workshop
- Sponsored by Electric Boat and CRUSER
- Goal – advance the Navy's Design for Undersea Warfare, focusing on relationships between manned submarines and unmanned undersea vehicles (UUVs)
- Junior officers from NPS and the fleet and early career engineers from Navy laboratories and other DoD partners

Technical Continuum/ Research Fair

- Showcase selected technologies identified in Sept 2012 and Mar 2013 Warfare Innovation Workshops

- 3rd Annual Robots in the Roses Research Fair

Sept 2012 Warfare Innovation Workshop → **Apr 2013 Technical Continuum** → Apr 2014 Field Experiment → June 2014 Research Expo → CRUSER Thread 2

Field Experimentation

Field Experimentation for technologies selected from the April 2013 Technical Continuum presentations

Research Expo: Washington DC

- Venue to showcase the results of CRUSER Innovation Thread #2, Advancing the Design of Undersea Warfare
  - Concept Generation:
    - Sept 2012 Warfare Innovation Workshop
    - Mar 2013 Warfare Innovation Workshop
  - Field Experimentation:
    - To be determined at the Apr 2013 Technical Continuum
  - Target is June 2014 at ONR

Experimentation

- MIO remote sensor control demonstration in Singapore
  - (FY11)
- Seaweb experimentation in coordination with Singapore
  - (FY12-13)
- UxS in Naval Operations Experiment
  - (FY13)

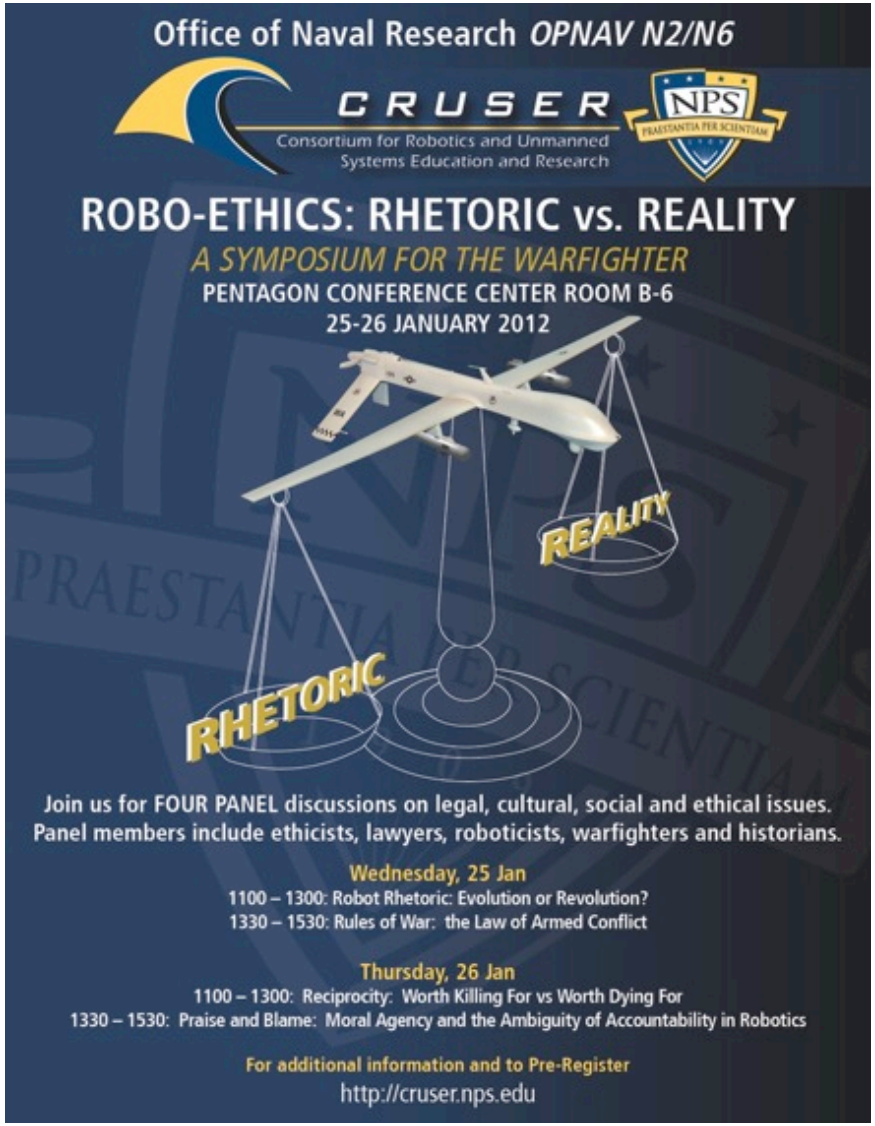
Controlling a SUV in Sweden from Singapore

Seaweb

Education

- CRUSER Robo-Ethics Continuing Education Series (RECES)
  Jan 2012/Sept 2013
- Catalog degree programs, short courses, and certificate programs country wide – FY13
- USNA Summer block internships – FY13
- Create short course programs as identified by community of interest - Continuous
- Align curricula for interdisciplinary autonomous systems education – Continuous
- S.T.E.M Outreach – Continuous

Robo-Ethics Continuation Series (RECES)



- **January 2012**
- Four panels, 2 days
- Over 100 participants from the DC area
- Commands represented included ONR, OSD, NAVAIR, NAVSEA, USNA, NPS, NWC, PEO LCS, NRL, DOS, JGRE, Navy Staff

- **September 2013**
- Enrichment Week event open to entire campus
- In conjunction Warfare Innovation Workshop
- 2-hour panel discussion on UxS ethical issues related to distributing future Naval air and surface forces

STEM Outreach Events

- OR Robotics Day
  - Aug 2010
- First Lego League of Monterey
  - Nov 2010/Apr 2011
- Monterey Academy of Oceanographic Sciences (MAOS)
  - Mar 2011
- "Girl's Day In"
  - Mar 2011
- Robots in the Roses Research Fair
  - Mar 2011/May 2012/May 2013
- Monterey County Science Fair Judges
  - Mar 2011
- Expanding your Horizons Career Fair
  - Nov 2011
- Brownie Troop 30608 – Mindstorm Robots
  - Jan 2012
- Cub Scout Pack 125 – Mindstorm Robots
  - Apr 2012
- La Mesa Elementary – Mindstorm Robots
  - Apr 2012
- Carmel High Robotics/Engineering Class Tours
  - May 2013

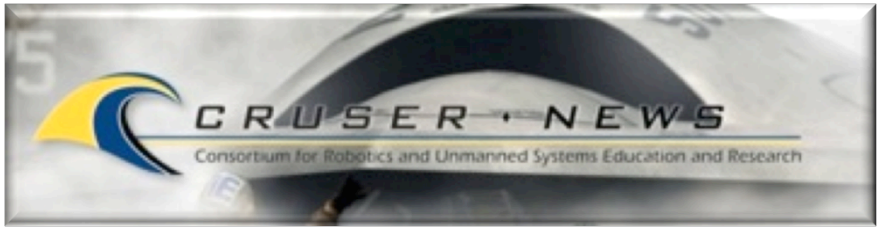
Robots in the Roses – Mar 2011

Girl's Day In– Mar 2011

Brownie Troop 30608 – Jan 2012

Collaboration

- CRUSER Community of Interest (CoI) data base
- CRUSER newsletter
  - http://CRUSER.nps.edu

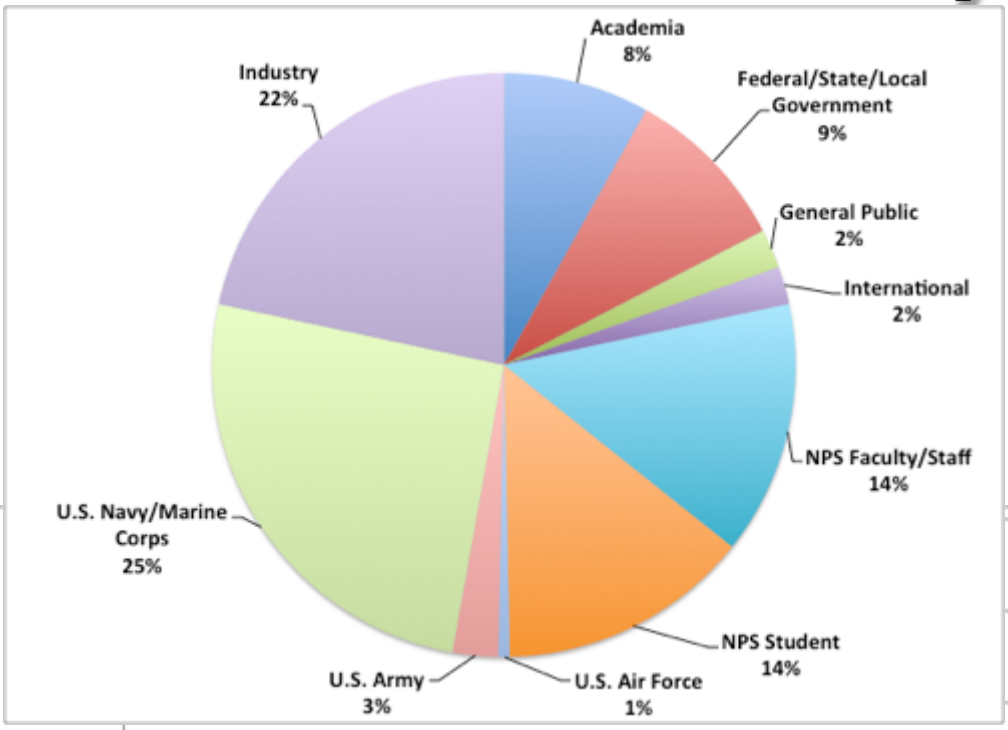


- Unclassified Website
  - CoI Listing
  - Calendar of Events
  - https://wiki.nps.edu/display/CRUSER/
- Classified Website
  - https://cruser.nps.navy.smil.mil
- Facebook Page
  - https://www.facebook.com/CRUSER.CoI

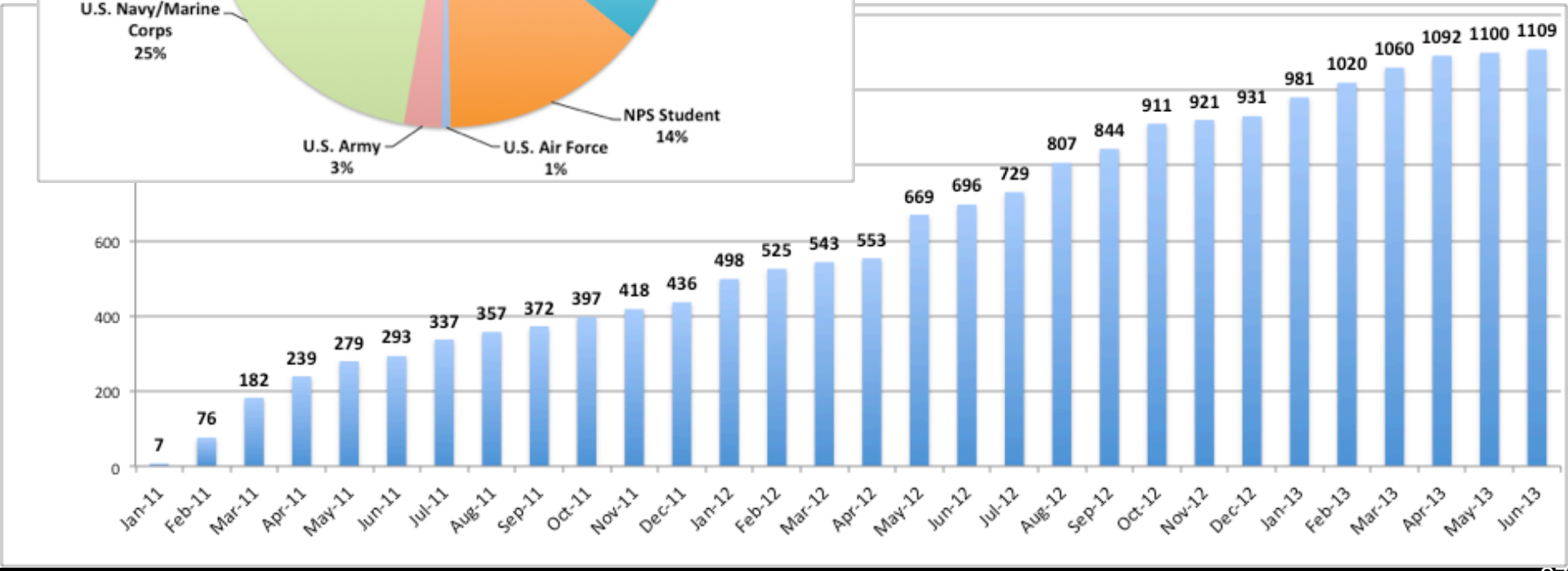
Collaboration

- Submission of thesis topics for NPS Students via Proposal Form on CRUSER Website available to entire Community of Interest - 48 submitted since Jan 2012
- 66 CRUSER thesis or Capstone projects have been completed from March 2011 through March 2013
- Monthly CRUSER CoI Meetings – VTC, Elluminate (webinar), and dial-in now available due to increasing call-in demand

Community of Interest



1109 Members and growing

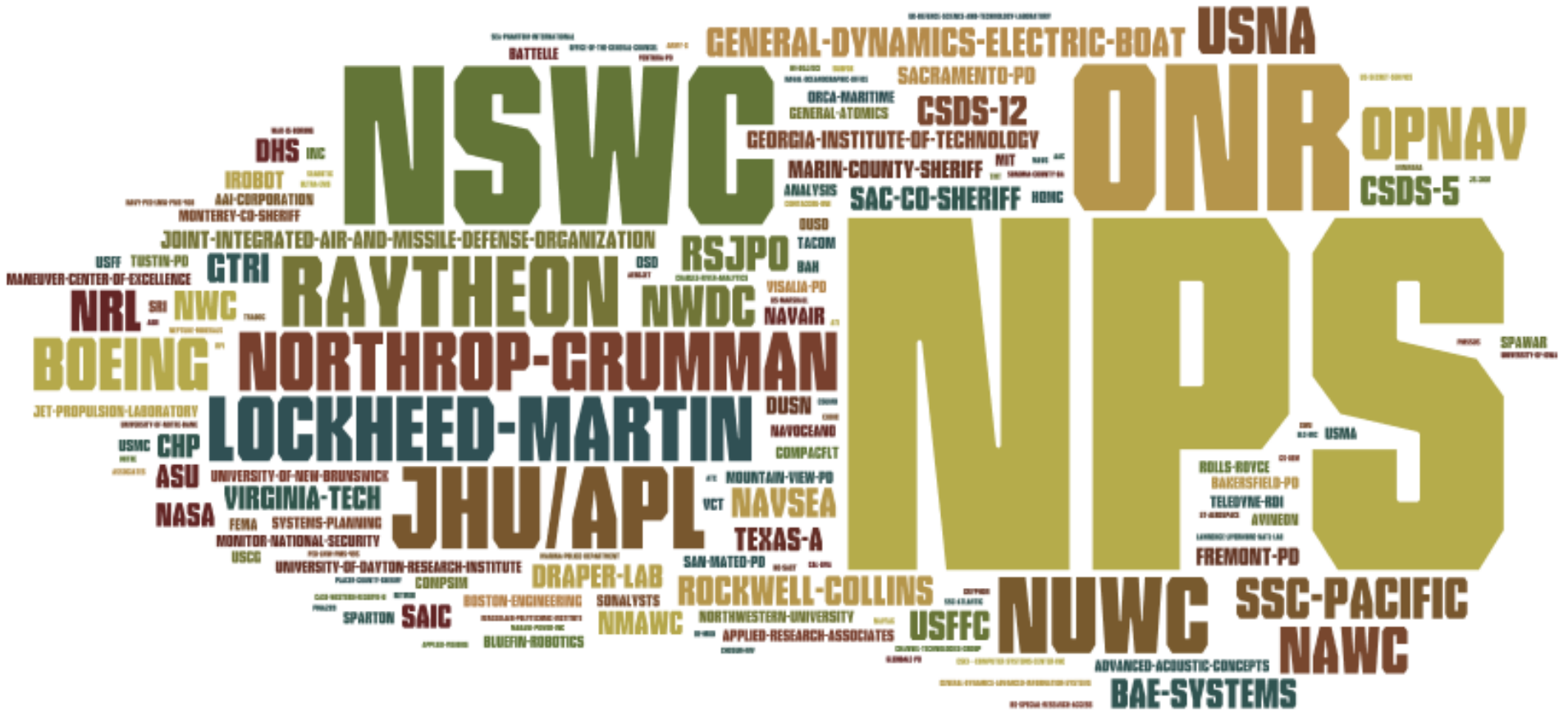


Community of Interest

Examples of CRUSER Member Organizations

- NPS
- NSWC
- NUWC
- ONR
- Northrop Grumman
- NWDC
- USNA
- SSC Pacific
- Raytheon
- Robotic Systems Joint Project Office
- JHU/Applied Physics Laboratory
- Lockheed Martin
- NRL
- OPNAV N2/N6
- Rockwell Collins
- USFFC
- DUSN
- General Dynamics Electric Boat
- Joint Integrated Air and Missile Defense Organization
- TACOM
- Teledyne RDI
- University of New Brunswick
- USFF
- Institute for Religion and Peace
- NAVAIR
- NAVSEA
- NMAWC
- NWC
- OPNAV
- SAIC
- Virginia Tech
- California Peace Officer Association
- Arizona State University
- Avineon, Inc.
- German Air Force
- COMPACFLT
- COMSUBDEVRON TWELVE
- Draper Laboratory
- Georgia Institute of Technology
- Georgia Tech Research Institute
- HQMC
- iRobot
- Jet Propulsion Laboratory
- MIT
- Northwestern University
- NSWC Carderock
- Orca Maritime, Inc.
- Systems Planning & Analysis, Inc

Community of Interest



Questions?

REFERENCE SLIDES

Concept Generation Events

- **Advanced Undersea Warfare Systems (AUWS) Warfare Innovation Workshop**
  - Involved Systems Engineering Analysis students as an innovation kick-off to their AUWS Capstone Project
- **Future Unmanned Naval Systems (FUNS) War game Competition**
  - Sponsored by NPS Chair for Undersea Warfare and BATTELLE
  - Concept generation for the deployment of unmanned systems in a future South China Sea scenario
  - All concepts published in a Technical Report

AUWS – Dec 2010

FUNS Wargame – Mar 2011

Aerial Combat Swarms: A Grand Challenge Competition

Swarm vs. Swarm Autonomous Systems

Dr. Timothy H. Chung
Systems Engineering Department
Naval Postgraduate School

Countering the Adversary's Autonomous Systems

Emerging threats of saturation attacks with unmanned systems

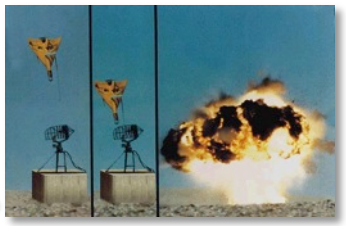
Fact: Proliferation of unmanned systems is rapidly accelerating
Fact: Lowering cost admits new players in asymmetric warfare

Problem: The adversary can potentially exploit *many inexpensive unmanned systems* to challenge and overwhelm our defensive capabilities

Case Study: Kamikaze UAVs

- Saturation attack profiles
- Persistent threat
- Minimal human-in-the-loop

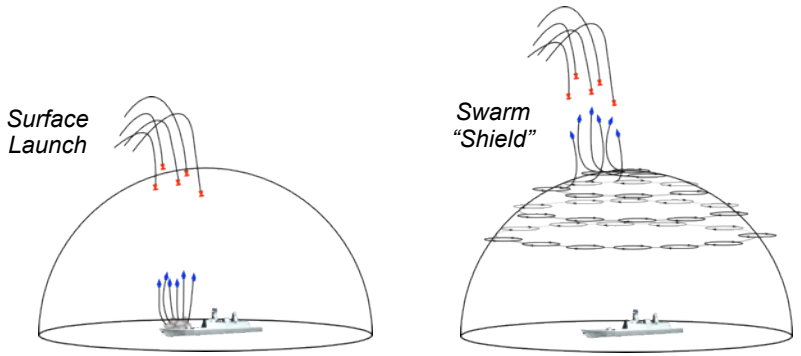
Harpy UAV engaging radar source



Defeating Inundation with Innovation

Utilize a defensive *swarm of UAVs*

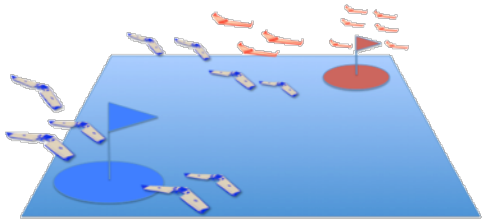
Future concept: Leverage defensive swarm of autonomous assets to find, fix, and engage the enemy swarm



Aerial Combat Swarm vs. Swarm UAV Competition

Inspire an ambitious grand challenge initiative

Goal: Live fly experiment **50** vs. **50** by **2015**!



***Aerial Combat Swarms* Competition:**

- Develop enabling capabilities for **attacking** the opponent's aerial bots and their home base while actively **defending** own home base
- Conduct **live-fly, outdoor competition** in tournament-style event
- Seek **innovations** in tactics, concepts of operations, autonomy algorithms, hardware platforms, etc.
- Provide **common standards** and infrastructure for rapid evolution

Revolutionizing Future Concepts for Swarm vs Swarm UAVs

Challenge and exceed existing frontiers in autonomous systems

Complex systems require *holistic* approach

- Offensive and defensive tactics
- Autonomy science
- Interoperability
- Human factors
- Manning and logistics
- Networked operations
- Business case analyses
- Platform capabilities
- …

***Aerial Combat* Swarm vs. Swarm UAV Competition**

A grand challenge where *tactics drive the technology*

Advanced Robotic Systems Engineering Laboratory (ARSENL)

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research

Email: *thchung@nps.edu*
Web: *http://faculty.nps.edu/thchung*

Call for Proposals

Selection Criteria

- NPS Student involvement
- Interdisciplinary, interagency, and partnerships with Naval labs
- Partnerships with other sponsors' funding
- Research related to unmanned systems' categories:
  - Technical
  - Organization and Employment
  - Social, Cultural, Political, Ethical and Legal
  - Experimentation
  - Defense against threat UxS capabilities
- New research area (Seed money to attract other contributors)
- Related to CRUSER mission thread
- Alignment with SECNAV's DoN Unmanned Systems

Amount Funded

- FY12 - $400k
- FY13 - $700K

FY 12
Funded Research Proposals

- Passive UxV Navigation using Visual Sensors
- Tropical Cyclone Reconnaissance with the Global Hawk: Operational Requirements, Benefits, and Feasibility
- Joint Optimization of Sensing and Sampling with Unmanned Undersea Vehicles
- Roadmap for Reduction of Total Ownership Cost (TOC) to Support Acquisition Decisions of Unmanned Autonomous Vehicle - Phase I
- Programming the Laws of Armed Conflict (LOAC) for Unmanned Systems
- Autonomous Multi-vehicle Tactical Surveillance and Support for Maritime Visit, Board, Search and Seizure Operations

FY 13
Funded Research Proposals

- The Use of Unmanned Systems for Environmental Sampling and Enhanced Battlespace Awareness in Support of Naval Operations
- Tactical Long Endurance Unmanned Air System (TaLEUAS)
- Networked Unmanned Systems Formation for Rapid Detection, Interdiction, and Expert Reachback in Maritime Interdiction Operations
- Support for NPS Seaglider Operations
- Comparative Analysis of X-47 UCAS & F-18 Squadron Manpower
- A Collaborative Diver Assistant for Underwater Operations
- Corporation of Navy's Ocean Data into UUV Path Planning with Obstacle Avoidance
- Experimental Unmanned Aircraft System (UAS) Interim Flight Clearances
- UAS Training and Pilot Certification Program

Examples of NPS Student Research

- Autonomy in Lethal UAVs
  - LT Matthew Larkin, USN
- Autonomous Surf Zone Robot
  - LT Steve Halle, USN and LT Jason Hickle, USN
- Multi-Agent Task Negotiation Among UAVs
  - Mr Michael Day
- Search on Optimized Graph Topologies
  - Maj Christian Klaus, German Army
- Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)
  - Maj Les Payton, USMC
- Business Case Analysis of Cargo UAS Capability in Support of Forward Deployed Logistics in OEF
  - Capt Troy Peterson, USMC
  - LT Jason Staley, USMC
- An Analysis of the Manpower Impact of Unmanned Aerial Vehicles (UAV's) on Subsurface Platforms
  - LT Thomas Futch, USN

Examples of NPS Student Research (cont)

- Advanced Undersea Warfare Systems
  - Systems Engineering Analysis Cross-Campus Study (SEA 17B)
- Agent-Based Simulation and Analysis of a Defensive UAV Swarm
  - Mauricio M. Munoz-Lieutenant, Chilean Navy
- Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)
  - LT Matthew Pawlenko, USN
- Self-propelled semi-submersibles: the next great threat to regional security and stability
  - LT Lance J Watkins, USN
- The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations
  - Capt Dino Cooper, USMC
- Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations
  - Maj Derek Snyder, USMC
- Autonomous Parafoils: Toward a Moving Target Capability
  - CDR Chas Hewgley, USN
- Unmanned Systems Capstone
  - Systems Engineering Analysis Cross-Campus Study (SEA 18B)

Maritime In Situ Sensing Inter-Operable Network

Joseph Rice, Naval Postgraduate School

Objectives

- Study noisy underwater environments
- Achieve acoustic communications through adverse channels
- Integrate U.S. "Seaweb" and Singapore "UNet" networks

Deliverables

Demonstrate *in situ* sensor networks in Singapore Strait

Milestones

- MISSION 2012 sea trials
- MISSION 2013 sea trials

Accomplishments to Date

Developed bilateral project plan with National University of Singapore

Payoff to the Navy

Enable distributed wireless architectures for Maritime Domain Awareness and Under-Sea Warfare